Minimally Invasive Plate Osteosynthesis (MIPO) of Humeral Shaft Fractures: Current State of the Art

Kevin Tetsworth

MD, FRACS

Department of Orthopaedic Surgery, Royal Brisbane Hospital, Herston, Australia

Department of Surgery, School of Medicine, University of Queensland, Australia

Erik Hohmann

FRCS, FRCS (Tr & Orth), MD, PhD

Medical School, University of Queensland, Australia

Faculty of Health, University of Pretoria, South Africa

Valiant Clinic/Houston Methodist Group, Dubai, United Arab Emirates

Vaida Glatt

PhD

University of Texas Health Science Center, San Antonio, Texas, USA

Abstract word count: 150

Manuscript word count: 3,952

Keywords: Minimal invasive plating; humeral shaft fractures; intramedullary nailing; plate fixation; outcomes; complications; meta-analysis; systematic review

Corresponding author: Erik Hohmann

Department of Orthopedic Surgery and Sports Medicine
Valiant Clinic/Houston Methodist Group
13th Street, City Walk – Dubai
United Arab Emirates
Email: ehohmann@hotmail.com

Abstract

Most closed humeral shaft fractures can be successfully managed nonsurgically. However, fractures for which closed treatment is unsuccessful are stabilized using either plates or intramedullary nails. There are shortcomings associated with each technique, including the potential complications of nonunion, infection, shoulder pain, and radial nerve injury. Minimally invasive plate osteosynthesis (MIPO), an innovative alternative treatment, is gaining in popularity. This technique is based on the anterior humeral shaft providing a relatively safe surface for plate application, and limited open exposures proximally and distally allow percutaneous insertion of the necessary implant. More than 40 articles have been published regarding MIPO, and it compares favorably to other available forms of treatment with excellent functional outcomes and a lower rate of iatrogenic radial nerve injury. Larger randomized controlled trials comparing this method with other accepted techniques, including nonsurgical management, are necessary to better define the role of MIPO in the management of humeral shaft fractures.

Introduction

Humeral shaft fractures are common injuries, and most can be successfully managed with appropriate conservative care.[1,2] Established surgical indications include failed nonsurgical treatment, polytrauma, open fractures, bilateral injuries, and ipsilateral forearm fractures.[1] When necessary, these are stabilized using either open plating (open reduction and internal fixation [ORIF]) or intramedullary nails, and there are proponents of both methods. Typically, ORIF involves an extensile approach, with concomitant soft-tissue stripping and local vascular disruption. Accordingly, the reported rate of nonunion varies between 3% and 20%,[1,3] with the additional risks of infection or iatrogenic radial nerve injury.[4,5] Open plating is often performed through a posterior approach, predisposing the vulnerable radial nerve to injury during the exposure.[1] Intramedullary nailing (IMN) of the humeral shaft was introduced to limit the risks of nonunion and radial nerve injury, potentially allowing these fractures to heal more rapidly by virtue of the use of a minimally invasive approach.[6,7] Unfortunately, clinical series of fractures stabilized with antegrade humeral nails often report debilitating shoulder complications related to their insertion through or adjacent to the rotator cuff, greater radiation exposure intraoperatively, and a higher rate of revision surgery.[1,3,8] Although surgery is sometimes required to maintain a satisfactory reduction and promote union,[1] there are recognized risks associated with each technique, including the potential complications of nonunion, infection, shoulder pain, and radial nerve injury. Direct comparisons between these two techniques reveal that both achieve comparable outcomes, yet there is still insufficient evidence to ascertain which of these two methods is preferable.[3,6-8]

An alternative method for the surgical management of humeral shaft fractures, minimally invasive plate osteosynthesis (MIPO), is rapidly gaining widespread popularity.[9-32] More than 40 articles on this technique have been published, including 5 comparative cohort studies,[9,10,14,25,33] 6 randomized controlled trials (RCTs),[34-39] and 4 meta-analyses.[40-43] Compared with either ORIF or IMN, this growing body of evidence now increasingly favors the MIPO technique as equally effective with less risk of complications.[14,34-38,40-43] Although the intent of ORIF is rigid fixation, the aim of any MIPO procedure is to achieve relative stability and secondary bone healing, using a locked plate to bridge the fracture site.[44,45] Indirect reduction of the fracture limits soft-tissue damage to preserve local vasculature and avoid disrupting early callus, resulting in a more biologically compatible form of plating.[44-46] The anterior surface of the humeral shaft provides a safe location for plate application,[47] using small incisions proximally and distally for percutaneous insertion of the necessary implant. Mounting evidence demonstrates that the use of this less invasive technique results in a high rate of rapid union with a decreased incidence of iatrogenic radial nerve injury.[14,40-43] This technique in-corporates the benefits of minimally invasive stabilization, as with an intramedullary nail, yet avoids the associated shoulder complications, while simultaneously minimizing the risk of the other complications associated with open plating.

Table 1, Summary of Humeral Minimally Invasive Plate Osteosynthesis Case Series Published in 2002 Through 2016

Years (References)	Studies (Countries)	Cases (n)	Non-union (n)	Infection (n)	Iatrogenic Nerve Injury (n)
2002-2006 (9, 18, 19, 24, 46)	5 (4)	41	1	2	2
2007-2011 (10, 11, 14, 15, 16, 22, 25, 28, 29, 30, 48, 51)	12 (10)	313	10	3	7
2012-2016 (13, 17, 20, 21, 26, 27, 50)	7 (4)	227	4	4	7
Totals	24 (15)	581	15 (2.6 %)	9 (1.5 %)	16 (2.8 %)

Early Reports, Case Series, and the Evolution of the Technique

Twenty-four clinical case series have been published on MIPO humeral plating over the past 15 years, collectively reporting on the results of .500 patients from 15 countries (Table 1). The pooled data reflect the favorable results consistently reported, with an aggregate nonunion rate of 2.6%, an infection rate of 1.5%, and an iatrogenic radial nerve injury rate of 2.8%. This compares very favorably to the complication rates reported for either ORIF or IMN, for which the risk of iatrogenic radial nerve palsy alone is reportedly as high as 10% to 20%.[4].

MIPO humeral plating first appeared as a natural extension of the minimally invasive approach to fracture fixation that already has demonstrated benefits in other anatomic sites.[44,45] For humeral fracture fixation, the method has gradually evolved to incorporate different implants and to reflect better appreciation of the subtleties of local anatomy. This technique was first reported by Dell'Oca,[48] who described two cases in a series of fractures treated with percutaneous helical plates. Livani and Belangero [20] published their initial experience in 2004 in a small series using conventional straight dynamic compression plates (DCPs) inserted percutaneously using an anterior approach. In their report on 15 cases, they noted only 1 nonunion, with that patient having a high-energy grade III open fracture.

MIPO humeral plating progressed further when Jiang et al[17] first recommended the use of a locking compression plate (LCP) in 2007 while reporting on 21 cases, 19 of which went on to unite. Schwarz et al[27] also suggested using an LCP, and although rapid primary union was achieved in 9 of the 11 patients treated, 1 patient experienced delayed union, and 1 patient experienced nonunion. In the only report to date from the United States, Ziran et al[32] subsequently reviewed 31 patients with 32 fractures who were treated with an LCP using the MIPO technique. They reported only one nonunion and observed no iatrogenic radial nerve injuries.

This move toward using LCPs instead of DCPs reinforced the principle of relative stability for this minimally invasive approach, providing a flexible yet stable mechanical construct. As such, the plate can be thought of an as internal fixator, and in spanning the fracture, it promotes callus formation by allowing controlled micromotion.[44,45] Although the LCP theoretically enhances stability, when Shen et al[28] compared their results in 26 cases performed with a DCP to 17 cases completed with an LCP, no clinically meaningful differences in outcomes were reported.

The largest single series of cases was reported by López-Arévalo et al,[49] with a total of 86 patients. There were three nonunions (3.5%) and three transient radial nerve palsies (3.5%) that resolved spontaneously. In this study, MIPO was associated with no cases of shoulder pain and an almost complete restitution of strength and range of motion of both the shoulder and elbow. Within 6 months, 96% of these patients had returned to their normal activities. Apivatthakakul et al[11] were also early advocates of the technique, performing a cadaver study to investigate the relationship of nerves at risk to the approaches necessary to create the anterior sub-muscular tunnel. They emphasized protecting the radial nerve from the distal end of the anterior plate by maintaining the forearm in supination during the surgical procedure.

The minimally invasive approach to humeral plating seems to be advantageous with regard to improved shoulder and elbow ROM postoperatively. When Kobayashi et al[18] reported a prospective series of 14 patients, they specifically investigated the time to full recovery of shoulder and elbow ROM, which was on average 19 and 60 days, respectively. Livani and Belangero[20] noted that shoulder ROM was normal in all patients, with only one having limitation of elbow flexion secondary to plate malposition. In a retrospective series, Mahajan et al[22] assessed the suitability of MIPO for humeral shaft fractures in athletes and laborers and documented that 94% were able to return to their original occupation or activity. In contrast, Kobayashi et al[18] attributed slower time to recovery of full elbow motion to either plate impingement or the process of splitting the brachialis on the approach. Plate impingement can be avoided by ensuring that the distal end of the plate is at or above the coronoid fossa.

Table 2. Results of Humeral MIPO Comparative Studies

Study	Cases (n) Implant	Non-union (n)	Infection (n)	Iatrogenic Nerve Injury (n)	Functional Outcome
An et al 2010 (China)	33 MIPO (17) ORIF (16)	0	0	ORIF (5)	Mean UCLA (MIPO 34.8; ORIF 34.4) Mean MEPS (MIPO 99.4; ORIF 99.7)
Oh et al 2012 (South Korea)	59 MIPO (29) ORIF (30)	MIPO (1) ORIF (3)	ORIF (1)	MIPO (1) ORIF (1)	Mean UCLA (MIPO 34.3; ORIF 33.8) Mean MEPS (MIPO 97.6; ORIF 97.0)
An et al 2012 (China)	34 MIPO (15) IMN (19)	0	0	0	Mean UCLA (MIPO 34.2; IMN 31.8) Mean MEPS (MIPO 100; IMN 97.6)
Wang et al 2015 (China)	48 MIPO (23) ORIF (25)	MIPO (1) ORIF (2)	0	MIPO (1) ORIF (3)	Mean Constant (MIPO 93.5; ORIF 95.3) Mean ASES (MIPO 94.9; ORIF 96.9)
Davies et al 2016 (Australia)	30 MIPO (15) IMN (15)	MIPO (1) IMN (4)	IMN (1)	IMN (3)	-

Comparative Studies

Over the past several years, five separate comparative trials have been conducted, as summarized in Table 2. Oh et al[25] retrospectively compared 29 MIPO cases to 30 ORIF cases, and the mean surigcal time in the MIPO group (110 minutes) was shorter than in the ORIF group (169 minutes). They concluded that MIPO can achieve equivalent radiologic and functional results with less surgical time, while reducing the risk of certain complications compared with ORIF.

Davies et al[14] compared MIPO to IMN in a retrospective case-match controlled study, with 15 patients in each group. They combined the results for three major complications (ie, infection, nonunion, iatrogenic radial nerve palsy) and observed that the pooled risk was more than seven times greater after IMN. They concluded that MIPO is a safe and effective technique for the management of displaced humeral shaft fractures, with a markedly reduced risk of major complications compared with IMN.

Remarkably, six different studies have been published from a single institution in China.[9,10,17,28,31,46] Two of these were case series,[17,31] two were direct comparisons to other techniques,[9,10] one compared results using either an LCP or a DCP,[28] and the last was a cadaver study to assess vascular disruption related to either ORIF or the MIPO approach.[46] The perfusion studies confirmed, as expected, that MIPO was superior to ORIF in maintaining local vascular integrity and would promote periosteal filling at the fracture site.[46] In 2010, An et al[10] compared MIPO with ORIF, with union in all cases and similar functional outcomes at 1 year. More importantly, they documented a notable difference in the rate of iatrogenic radial nerve palsies, with none in the MIPO group and 5 of 16 (31.3%) in the ORIF group. In 2012, An et al[9] compared MIPO with IMN and again noted that all fractures united in both groups, with a single delayed union in the MIPO arm. Shoulder function at final review was better in the MIPO group than the IMN group, but this difference was not clinically meaningful. However, the authors noted that MIPO was technically more demanding and required 23 minutes of additional surgical time (P , 0.05)..

Finally, Wang et al[33] again compared MIPO with ORIF, obtaining CT scans on all[48] patients to assess rotational alignment postoperatively. They also documented a decreased rate of radial nerve palsy and nonunion when using this less invasive technique. However, they observed a high prevalence of rotational malreduction (exceeding 20° in 39% of patients) after MIPO, which has not been reported previously by any other group of surgeons.

Randomized Controlled Trials

Six randomized controlled trials have been completed to date, and the results are summarized in Table 2. Lian et al[36] published the first randomized controlled trial comparing humeral shaft MIPO to both antegrade and retrograde IMN. They randomized 47 humerus fractures to either MIPO (n=24) or IMN (n=23), and reported comparable results for most outcomes. They noted 1 non-union after MIPO and 2 non-unions following IMN, and reported 1 angular malunion in both groups. There were no deep infections in either group, while there was 1 iatrogenic radial nerve injury after MIPO and 3 following IMN. Operative time was shorter with MIPO, and shoulder function was also significantly better after MIPO. They concluded that humeral shaft fractures can be effectively treated with either MIPO or IMN, but believe MIPO is the better option for complex fractures while IMN remains a good option for relatively simple fractures. Benegas et al[32] randomized 40 humeral shaft fractures to either MIPO (n=21) or IMN (n=19), finding that all fractures healed with the exception of one non-union following IMN. Malunions were not observed and no differences in shoulder or elbow function. Surgical time was equivalent between the 2 groups, but there was significantly more use of fluoroscopy with IMN compared to MIPO. They concluded humeral shaft MIPO is a safe and effective technique that resulted in less radiation exposure for the surgeon, with comparable shoulder function achieved using either method.

Kim et al[37] conducted a multi-center randomized controlled trial on 68 patients comparing MIPO (n=36) to ORIF (n=32). Union was achieved by 20 weeks in all but one patient following ORIF (31/32) and in all 36 patients after MIPO (p=0.471); the delayed union in the ORIF group later healed spontaneously. In all 68 patients the fractures healed with less than 10 degrees of angular deformity and less than 1 cm of shortening. There were no post-operative infections in either group, and post-operative radial nerve palsy was only noted in a single ORIF patient (3%). Operative time was longer with ORIF compared to MIPO, although this was not significantly different. They reported comparable functional outcomes for both the shoulder and elbow, and concluded MIPO is equivalent to ORIF as a safe and effective technique for managing humeral shaft fractures when performed by surgeons familiar with the technique. Hadhoud et al[34] completed a randomized controlled trial comparing MIPO to ORIF for humeral shaft fractures in 30 patients. Union was achieved in all 15 MIPO patients and 14 of 15 ORIF patients, while the mean time to union was similar. Again, the mean operative time for the MIPO group was shorter than the ORIF group ($p < 0.0001$). They reported one postoperative radial nerve palsy following MIPO and two after ORIF. The MIPO technique achieved comparable results to ORIF, with reduced perioperative complications and a decreased operative time. Esmailiejah et al[33] conducted a prospective randomized study comparing MIPO to ORIF in 65 patients. The median time to union was shorter with MIPO compared to ORIF, while the time of surgery, as well as functional outcomes for shoulder and elbow, were no different. The incidence of infection, non-union, and iatrogenic radial nerve injury was lower with MIPO, but this difference was not significant. In their opinion the decreased time to union, the trend towards fewer complications, and the comparable clinical outcomes made MIPO a more attractive alternative to ORIF for fractures of the mid-distal humerus.

Most recently, Matsunaga et al[39] completed the first RCT comparing MIPO stabilization and functional bracing for the treatment of humeral shaft fractures. Rather than evaluate the potential benefit of MIPO with respect to other surgical alternatives, this landmark study is the first RCT to compare operative and non-operative treatment of humeral shaft fractures. In an attempt to minimize observer bias, additional measures were taken to attempt to conceal the treatment from the assessors. This study demonstrated patients treated by MIPO stabilization had a lower nonunion rate (0%) compared to those managed non-operatively in a brace (15%). In addition, they observed less radiographic deformity in the coronal plane in those treated by MIPO, as well as a statistically significant advantage over functional bracing in terms of the self-reported DASH score at 6 months. However, the DASH score was just 6 points better, and only the nonunion rate is likely to be clinically meaningful.

Systematic Reviews and Meta-Analyses

Four systematic reviews and meta-analyses regarding MIPO for humeral shaft fractures have already appeared. Yu et al[43] conducted a meta-analysis comparing humeral shaft MIPO to ORIF, although they only found a limited number of high quality studies (2 RCTs and 3 non-RCTs) that met their inclusion criteria. There was a significantly lower incidence of iatrogenic radial nerve palsy in patients treated by MIPO. There was no significant difference in the risk of developing non-union, delayed union, malunion, hardware failure, or infection between the groups. Similarly, there was no difference in operative time or functional outcome scores. They concluded MIPO is a safe and effective technique for stabilizing humeral shaft fractures, with a decreased risk of iatrogenic radial nerve palsy compared to ORIF.

Hohmann et al[40] also completed a systematic review and meta-analysis of MIPO compared to either ORIF or IMN for humeral shaft fractures. In their analysis 8 studies met the inclusion criteria, and again the paucity of high quality studies was recognized. In this study, the pooled estimate for clinical outcomes demonstrated that MIPO resulted in significantly better function. Likewise, they demonstrated that the ORIF/IMN group had a significantly higher complication rate (OR 0.507, p=0.02). Specifically, there were a significantly higher number of nerve injuries following ORIF/IMN (OR 0.302, p=0.02). Their analysis of the literature demonstrated MIPO results in better clinical outcomes with a lower rate of complications compared to alternative surgical techniques and is a safe and effective treatment option for humeral shaft fractures, while being comparable, if not superior, to the other available methods.

Hu et al[41] used a meta-analysis to compare MIPO to alternative forms of surgical stabilization of displaced humeral shaft fractures. They analyzed 8 studies, including 4 RCTs, 2 prospective trials, and 2 retrospective cohort trials. They identified no significant difference between MIPO and either ORIF or IMN with regard to operative time, union rate, or time to union. However, MIPO had a reduced rate of complications including iatrogenic radial nerve palsy compared to ORIF, and better adjacent joint motion compared to IMN.

Most recently, Qiu et al[42] published their Bayesian meta-analysis comparing MIPO, ORIF, and IMN of humeral shaft fractures. This is the most comprehensive meta-analysis to date, incorporating 17 RCTs or prospective studies. The pooled results showed that the rates of radial nerve injury were lowest for MIPO, intermediate for ORIF, and highest for IMN. They also demonstrated the risk of non-union was lowest for MIPO, intermediate for ORIF, and highest for IMN. They concluded the current evidence demonstrates that MIPO is the optimum choice for the treatment of humeral shaft fractures, and that ORIF is superior to IMN.

Indications and Contraindications

As with other techniques of surgical stabilization, the indications for MIPO of humeral shaft fractures include failed non-operative treatment, poly-trauma, certain open fractures, bilateral injuries, floating shoulders, and ipsilateral forearm fractures[1]. Contraindications include pathological fractures, advanced osteoporosis, associated vascular injuries, severe soft tissue compromise, active local infection, and radial nerve palsy following a penetrating injury. Anterior humeral MIPO can be equally applied to transverse fractures, spiral fractures, segmental fractures, and comminuted fractures, recognizing some fractures would inevitably be more difficult to control by any method. With minor modifications of the implants selected and the specifics of the technique, MIPO methods can be utilized for fractures extending from the surgical neck of the humerus to within 10-12 cm of the elbow joint line. Humeral shaft fractures in the proximal third are more difficult to control, and the deltoid acts to displace the fracture site. Slight extension of the proximal approach facilitates a more anatomic reduction, and judicious use of additional screws will augment stability. Although some surgeons still consider radial nerve palsy an indication for surgical exploration and ORIF, the current consensus for closed fractures is an expectant policy of observation and monitoring nerve injuries unless they were the direct result of an attempted reduction maneuver[49]. MIPO humeral fracture stabilization can still be employed in the presence of a pre-existing radial nerve palsy, anticipating the vast majority will resolve spontaneously over the ensuing period of weeks.

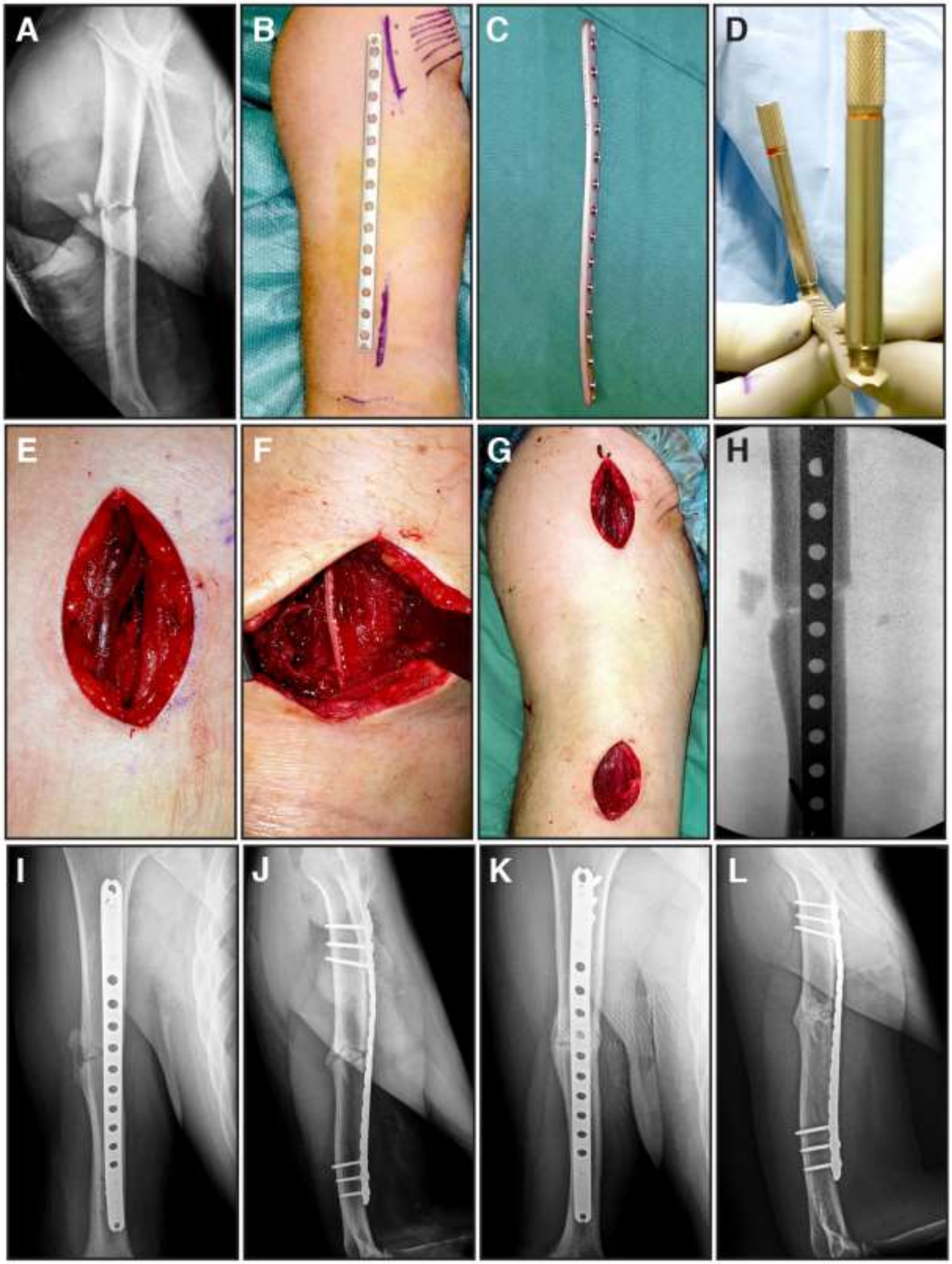
A
B
C
D
E
F
G
H
I
J
K
L

Figure 1 This 37 yo right hand dominant man sustained polytrauma in a motorbike accident. His injuries included a right floating elbow, with an ipsilateral both bone forearm fracture and (A) a closed mid-shaft right humeral shaft fracture; (B) a 14-hole locking compression plate was selected, with adequate length to span the fracture and provide sufficient mechanical control; (C) this plate was pre-contoured to closely match the normal anterior humeral cortical surface and serve as a better template for restoring anatomic alignment, by bending the plate with subtle opposing curves proximal and distal; (D) the plate is internally rotated 15-20º through its mid-portion, consistent with normal anatomy; (E) the proximal incision is 4-5 cm in length at the level of the pectoralis major insertion, preserving the cephalic vein, as an extension of the delto-pectoral approach; (F) the distal incision is 4-5 cm in length just proximal to the antecubital crease, and the lateral antebrachial cutaneous nerve of the forearm is identified beneath the biceps before bluntly splitting the brachialis; (G) a submuscular extra-periosteal tunnel is created to connect the two incisions; (H) a provisional closed reduction is performed prior to insertion of the plate, generally from distal to proximal; (I) AP radiograph at 8 weeks, demonstrating early callus, with minor varus <3º; (J) lateral radiograph at 8 weeks, confirming near anatomic alignment; (K) AP radiograph at 1 year, demonstrating mature bridging callus; (L) lateral radiograph at 1 year, confirming solid union.

Surgical Technique

The surgical technique has been explained in detail in many prior publications, with the manuscript by Apivatthakakul et al[12] providing the most complete description with extensive illustrations. Most authors consistently follow a common set of principles[10, 12, 14. 17-20, 22, 23, 25-29, 31-35, 49- 51], with minor variations based on individual experience (Figure 1A-L).

The patient is positioned supine with the fractured extremity on a radiolucent table, and the elbow supported in mild flexion to relax the biceps. This facilitates reduction and increases the exposure possible through the limited incisions, especially distally. MIPO humeral plating requires only two 4-5 centimeter incisions on the anterior aspect of the arm, proximal and distal (Figure 1B, G). The proximal incision is the inferior portion of the delto-pectoral approach, using the biceps groove and pectoralis tendon as landmarks and exposing the proximal diaphysis immediately lateral to the biceps tendon (Figure 1E). The distal incision begins 1-2 centimeters proximal to the antecubital crease, and extends proximally for 4-5 centimeters in the midline (Figure 1F). The interval between biceps and brachialis is identified laterally, and the biceps is retracted medially. Care is taken to identify and protect the lateral antebrachial cutaneous nerve laying beneath. The brachialis is then split longitudinally by blunt dissection to bone, limiting dissection or retractors laterally to avoid the radial nerve at this level. It is important to keep the forearm supinated throughout the procedure to protect the radial nerve in the distal portion of the approach[11,20,34,47] .

Provisional fracture reduction is performed manually under fluoroscopic control, and a submuscular extraperiosteal tunnel is developed that connects the two incisions (Figure 1H). Many authors recommend using a narrow 4.5 mm LCP, although our preference is for a 3.5 mm LCP. Most authors also report using a straight LCP, and rely on the locking screws to maintain the reduction achieved intra-operatively[12,17,23,31]. However, to achieve the most anatomic reduction possible the plate can be pre-contoured to more closely correspond to the surface of the anterior cortex of the normal humerus (Figure 1C).

After introducing the plate, the proximal segment is aligned with the implant as anatomically as possible and a single unlocked screw is used to reduce the plate to the anterior humeral cortex. Fixation is augmented with two additional locked screws, and the plate then used to assist with the reduction[29]. The plate is next aligned with the distal segment as anatomically as possible, and the fracture reduction is checked fluoroscopically. Prior to initiating distal fixation the reduction is assessed critically and efforts made to correct any malalignment, recognizing rotation may be the most difficult aspect to judge correctly[33]. Manual compression of the fracture site is recommended to limit the possibility of distraction resulting in delayed union. After provisional fixation is obtained, rotation is best assessed by direct comparison with the rotational excursion of the undraped opposite limb. A single unlocked cortical screw is used to reduce the plate to the distal humerus, and distal fixation is finally augmented with two additional locked screws.

A temporary external fixator can be used intra-operatively to control the fracture in the coronal plane [17,19,24,25,32], but most surgeons achieve very satisfactory alignment using standard closed reduction techniques. When a radial nerve injury is identified pre-operatively Livani et al[19], has advocated formal release of the nerve through an accessory third incision. However, most authors agree the radial nerve should not be explored routinely, and these generally recover spontaneously without active intervention.

The choice of implant (ie, 3.5-mm LCP or long proximal humerus locking plate) and specifics with regard to postoperative rehabilitation can be determined based on the fracture configuration and location, as well as details with respect to the surgical indications, quality of the reduction, and the strength of screw purchase in any individual patient. Patients are generally instructed to use a sling for comfort as necessary for the first 2 weeks. Early active/assisted range of motion of the shoulder and elbow is encouraged immediately, without restrictions. Full extension of the elbow is an early priority, and activity is increased as limited by pain. Minor functional limitations are continued until solid bridging callus is visible radiographically. Return to sports and completely unrestricted activity is generally permissible within 4 to 6 months.

Summary

The focus of this review was to intro-duce the MIPO technique for humeral shaft fractures, while summarizing the available literature regarding the indications, contraindications, clinical outcomes, and potential benefits. More than 40 relevant articles have already been published, generally favoring MIPO compared with alternative methods of surgical stabilization (ie, ORIF, IMN), including 6 RCTs[34-38] and 4 meta-analyses.40-43 These findings are not surprising because previous studies using MIPO for the lower limbs have also demonstrated a decreased rate of nonunion and diminished need for further surgery.[44,45] Leaving the early fracture callus undisturbed while preserving local vasculature theoretically contributes to accelerated union.[44,45] However, the greatest advantage seems to be the diminished risk of complications, particularly reducing the rate of iatrogenic radial nerve palsy.[14,40-43].

Based on the available literature, MIPO now holds genuine promise as an alternative method of humeral shaft fracture fixation. The current literature consistently favors MIPO compared to other methods of surgical stabilization, and it offers a middle ground between ORIF and IMN that incorporates some of the best aspects of each. While many cases can be managed non-operatively, MIPO provides another option for managing selected humeral shaft fractures that may benefit from surgery. The MIPO technique compares favorably to other available forms of treatment with excellent functional outcomes, a lower rate of iatrogenic radial nerve injury, and a high rate of rapid union. However, larger randomized controlled trials comparing this method to other accepted techniques, including non-operative management, are necessary to better define the role of MIPO for humeral shaft fractures.

References

Evidence-based Medicine:Levels of evidence are described in the table of contents. In this article, references 3-6, 32-37, and 49 are level I studies. References 38-41 are level II studies. References 7, 8, 12, 23, and 31 are level III studies. References 2, 9-11,13-22, 24-30, 45-48, 50, and 51 are level IV studies.

References printed in bold type are those published within the past 5years.

1. Carroll EA, Schweppe M, Langfitt M, et al: Management of humeral shaft fractures. *J Am Acad Orthop Surg* 2012; 20(7): 423-33.
2. Sarmiento A, Zagorski JB, Zych GA, et al: Functional bracing for the treatment of fractures of the humeral diaphysis. *J Bone Joint Surg Am* 2000; 82(4): 478-86.
3. Bhandari M, Devereaux PJ, McKee MD, Schemitsch EH: Compression plating versus intramedullary nailing of humeral shaft fractures--a meta-analysis. *Acta Orthop* 2006; 77(2): 279-84.
4. **Claessen FM, Peters RM, Verbeek DO, et al: Factors associated with radial nerve palsy after operative treatment of diaphyseal humeral shaft fractures. J Shoulder Elbow Surg 2015;24:e307-e311.**
5. Shao YC, Harwood P, Grotz MR, et al: Radial nerve palsy associated with fractures of the shaft of the humerus: A systematic review. J Bone Joint Surg Br 2005;87: 1647-1652.
6. McCormack RG, Brien D, Buckley RE, et al: Fixation of fractures of the shaft of the humerus by dynamic compression plate or intramedullary nail. A prospective, randomised trial. *J Bone Joint Surg Br* 2000; 82(3): 336-9.
7. Chapman JR, Henley MB, Agel J, Benca PJ: Randomized prospective study of humeral shaft fracture fixation: intramedullary nails versus plates. *J Orthop Trauma* 2000; 14(3): 162-6.
8. Ouyang H, Xiong J, Xiang P, et al: Plate versus intramedullary nail fixation in the treatment of humeral shaft fractures: an updated meta-analysis. *J Shoulder Elbow Surg* 2013; 22(3): 387-95.
9. An Z, He X, Jiang C, Zhang C: Treatment of middle third humeral shaft fractures: minimal invasive plate osteosynthesis versus expandable nailing. *Eur J Orthop Surg Traumatol* 2012; 22(3): 193-199.
10. An Z, Zeng B, He X, et al: Plating osteosynthesis of mid-distal humeral shaft fractures: minimally invasive versus conventional open reduction technique. *Int Orthop* 2010; 34(1): 131-5.
11. Apivatthakakul T, Arpornchayanon O, Bavornratanavech S: Minimally invasive plate osteosynthesis (MIPO) of the humeral shaft fracture. Is it possible? A cadaveric study and preliminary report. *Injury* 2005; 36(4): 530-8.
12. Apivatthakakul T, Phornphutkul C, Laohapoonrungsee A, Sirirungruangsarn Y: Less invasive plate osteosynthesis in humeral shaft fractures. *Oper Orthop Traumatol* 2009; 21(6): 602-13.

13. Concha JM, Sandoval A, Streubel PN: Minimally invasive plate osteosynthesis for humeral shaft fractures: are results reproducible? *Int Orthop* 2010; 34(8): 1297-305.
14. **Davies G, Yeo G, Meta M, et al: Case-Match Controlled Comparison of Minimally Invasive Plate Osteosynthesis and Intramedullary Nailing for the Stabilization of Humeral Shaft Fractures. *J Orthop Trauma* 2016; 30(11): 612-617.**
15. **Deepak S, Holagundi L, Dayanand, et al: Minimally invasive percutaneous plate osteosynthesis by anterior approach for fracture shaft of humerus. *Int J Orthop Sci* 2016; 2(3): 22-26.**
16. Ji F, Tong D, Tang H, et al: Minimally invasive percutaneous plate osteosynthesis (MIPPO) technique applied in the treatment of humeral shaft distal fractures through a lateral approach. *Int Orthop* 2009; 33(2): 543-7.
17. Jiang R, Luo CF, Zeng BF, Mei GH: Minimally invasive plating for complex humeral shaft fractures. *Arch Orthop Trauma Surg* 2007; 127(7): 531-5.
18. Kobayashi M, Watanabe Y, Matsushita T: Early full range of shoulder and elbow motion is possible after minimally invasive plate osteosynthesis for humeral shaft fractures. *J Orthop Trauma* 2010; 24(4): 212-6.
19. Lee HJ, Oh CW, Oh JK, et al: Minimally invasive plate osteosynthesis for humeral shaft fracture: a reproducible technique with the assistance of an external fixator. *Arch Orthop Trauma Surg* 2013; 133(5): 649-57.
20. Livani B,Belangero WD: Bridging plate osteosynthesis of humeral shaft fractures. *Injury* 2004; 35(6): 587-95.
21. Livani B, Belangero WD, Castro de Medeiros R: Fractures of the distal third of the humerus with palsy of the radial nerve: management using minimally-invasive percutaneous plate osteosynthesis. *J Bone Joint Surg Br* 2006; 88(12): 1625-8.
22. **Mahajan AS, Kim YG, Kim JH, et al: Is Anterior Bridge Plating for Mid-Shaft Humeral Fractures a Suitable Option for Patients Predominantly Involved in Overhead Activities? A Functional Outcome Study in Athletes and Manual Laborers. *Clin Orthop Surg* 2016; 8(4): 358-366.**
23. Malhan S, Thomas S, Srivastav S, et al: Minimally invasive plate osteosynthesis using a locking compression plate for diaphyseal humeral fractures. *J Orthop Surg (Hong Kong)* 2012; 20(3): 292-6.
24. Numbela BX, Aceves LH, Gonzalez AB, Castro CT: [Minimally invasive surgery in diaphyseal humeral fractures with helicoidal plate. One year result in seven patients]. *Acta Ortop Mex* 2007; 21(5): 239-46.
25. Oh CW, Byun YS, Oh JK, et al: Plating of humeral shaft fractures: comparison of standard conventional plating versus minimally invasive plating. *Orthop Traumatol Surg Res* 2012; 98(1): 54-60.
26. Pospula W,Abu Noor T: Percutaneous fixation of comminuted fractures of the humerus: initial experience at Al Razi hospital, Kuwait. *Med Princ Pract* 2006; 15(6): 423-6.
27. Schwarz N, Windisch M, Mayr B: Minimally Invasive Anterior Plate Osteosynthesis in Humeral Shaft Fractures. *Eur J Trauma Emerg Surg* 2009; 35(3): 271-6.
28. Shen L, Qin H, An Z, et al: Internal fixation of humeral shaft fractures using minimally invasive plating: comparative study of two implants. *Eur J Orthop Surg Traumatol* 2013; 23(5): 527-34.

29. Shin SJ, Sohn HS, Do NH: Minimally invasive plate osteosynthesis of humeral shaft fractures: a technique to aid fracture reduction and minimize complications. *J Orthop Trauma* 2012; 26(10): 585-9.
30. Spagnolo R, Pace F, Bonalumi M: Minimally invasive plating osteosynthesis technique applied to humeral shaft fractures: the lateral approach. *Eur J Orthop Surg Traumatol* 2010; 20(3): 205-210.
31. Zhiquan A, Bingfang Z, Yeming W, et al: Minimally invasive plating osteosynthesis (MIPO) of middle and distal third humeral shaft fractures. *J Orthop Trauma* 2007; 21(9): 628-33.
32. Ziran BH, Kinney RC, Smith WR, Peacher G: Sub-muscular plating of the humerus: an emerging technique. *Injury* 2010; 41(10): 1047-52.
33. **Wang C, Li J, Li Y, et al: Is minimally invasive plating osteosynthesis for humeral shaft fracture advantageous compared with the conventional open technique? *J Shoulder Elbow Surg* 2015; 24(11): 1741-8.**
34. **Benegas E, Ferreira Neto AA, Gracitelli ME, et al: Shoulder function after surgical treatment of displaced fractures of the humeral shaft: a randomized trial comparing antegrade intramedullary nailing with minimally invasive plate osteosynthesis. *J Shoulder Elbow Surg* 2014; 23(6): 767-74.**
35. **Esmailiejah AA, Abbasian MR, Safdari F, Ashoori K: Treatment of Humeral Shaft Fractures: Minimally Invasive Plate Osteosynthesis Versus Open Reduction and Internal Fixation. *Trauma Mon* 2015; 20(3): e26271.**
36. **Hadhoud MM, Darwish AE, Mesriga MM: Minimally invasive plate osteosynthesis versus open reduction and plate fixation of humeral shaft fractures. *Menoufia Med J* 2015; 28(1): 154-161**.
37. **Kim JW, Oh CW, Byun YS, et al: A prospective randomized study of operative treatment for noncomminuted humeral shaft fractures: conventional open plating versus minimal invasive plate osteosynthesis. *J Orthop Trauma* 2015; 29(4): 189-94.**
38. Lian K, Wang L, Lin D, Chen Z: Minimally invasive plating osteosynthesis for mid-distal third humeral shaft fractures. *Orthopedics* 2013; 36(8): e1025-32.
39. **Matsunaga FT, Tamaoki MJ, Matsumoto MH, et al: Minimally Invasive Osteosynthesis with a Bridge Plate Versus a Functional Brace for Humeral Shaft Fractures: A Randomized Controlled Trial. *J Bone Joint Surg Am* 2017; 99(7): 583-592.**
40. **Hohmann E, Glatt V, Tetsworth K: Minimally invasive plating versus either open reduction and plate fixation or intramedullary nailing of humeral shaft fractures: a systematic review and meta-analysis of randomized controlled trials. *J Shoulder Elbow Surg* 2016; 25(10): 1634-42.**
41. **Hu X, Xu S, Lu H, et al: Minimally invasive plate osteosynthesis vs conventional fixation techniques for surgically treated humeral shaft fractures: a meta-analysis. *J Orthop Surg Res* 2016; 11(1): 59.**
42. **Qiu H, Wei Z, Liu Y, et al: A Bayesian network meta-analysis of three different surgical procedures for the treatment of humeral shaft fractures. *Medicine (Baltimore)* 2016; 95(51): e5464.**
43. **Yu BF, Liu LL, Yang GJ, et al: Comparison of minimally invasive plate osteosynthesis and conventional plate osteosynthesis for humeral shaft fracture: A meta-analysis. *Medicine (Baltimore)* 2016; 95(39): e4955.**

44. Farouk O, Krettek C, Miclau T, et al: Minimally invasive plate osteosynthesis and vascularity: preliminary results of a cadaver injection study. *Injury* 1997; 28 Suppl 1A7-12.
45. Stoffel K, Dieter U, Stachowiak G, et al: Biomechanical testing of the LCP--how can stability in locked internal fixators be controlled? *Injury* 2003; 34 Suppl 2B11-9.
46. **Xue Z, Jiang C, Hu C, et al: Effects of different surgical techniques on mid-distal humeral shaft vascularity: open reduction and internal fixation versus minimally invasive plate osteosynthesis. *BMC Musculoskelet Disord* 2016; 17370.**
47. Livani B, Belangero W, Andrade K, et al: Is MIPO in humeral shaft fractures really safe? Postoperative ultrasonographic evaluation. *Int Orthop* 2009; 33(6): 1719-23
48. Fernandez Dell'Oca AA: The principle of helical implants: unusual ideas worth considering. Case studies. *Injury* 2002; 33 Suppl 1SA29-40.
49. Lopez-Arevalo R, de Llano-Temboury AQ, Serrano-Montilla J, et al: Treatment of diaphyseal humeral fractures with the minimally invasive percutaneous plate (MIPPO) technique: a cadaveric study and clinical results. *J Orthop Trauma* 2011; 25(5): 294-9.
50. Shetty MS, Kumar MA, Sujay K, et al: Minimally invasive plate osteosynthesis for humerus diaphyseal fractures. *Indian J Orthop* 2011; 45(6): 520-6.
51. **Huri G, Bicer OS, Ozturk H, et al: Functional outcomes of minimal invasive percutaneous plate osteosynthesis (MIPPO) in humerus shaft fractures: A clinical study. Acta Orthop Traumatol Turc 2014;48: 406-412.**